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Using hyperdocuments to manage scientific knowledge: the prototype Encyclopedia of Southern Appalachian Forest Ecosystems

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Abstract

Despite the overwhelming body of research available on the ecology and management of Southern Appalachian forests, a gap exists between what scientists know and what the management community is able to apply on the ground. Most research knowledge still resides in highly technical, narrowly focused research publications housed in libraries. The internet, combined with increasingly sophisticated hyperdocument authoring systems, makes web-based hyperdocuments a practical and affordable way to manage this scientific knowledge. The USDA Forest Service developed the Encyclopedia of Southern Appalachian Forest Ecosystems (ESAFE; http://www.forestencyclopedia.net), a hyperdocument-based encyclopedia system available on the internet, to address this need for more accessible, understandable, condensed, and synthesized research knowledge. This project aims to synthesize what we know scientifically about the management and ecology of Southern Appalachian forest ecosystems, organize it logically, and make it universally available at no cost to users. ESAFE is composed of original summaries of hundreds of topic areas compiled from over 5000 literature sources by over 15 authors specifically for this purpose. Presently, ESAFE has over 1100 pages of content that includes over 150 tables, 150 figures, 3000 internal hyperlinks, and 1800 external hyperlinks. Unlike most internet-based hyperdocuments, quality control of the encyclopedia is ensured through a complete peer-review process similar to traditional scientific journals. The encyclopedia is built upon a dynamic content management system (CMS), developed using Zope software, that provides a platform for authoring, editing, reviewing, publishing, and updating content directly through the internet. This CMS creates a mechanism for updating the site with peer-review content directly through the internet, so that the knowledge base can be continually updated, expanded, and improved. Using tools like ESAFE, busy forest managers can more easily find answers to questions from their own desks. It has been favorably evaluated by a diverse group of

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land managers, the general public, and ecosystem scientists. It is also currently being used as a prototype for several other forestry-related hypertext encyclopedias.

Keywords: Knowledge management; Hyperdocuments; Southern Appalachians; Content management systems; Peer-review

1. Introduction

Many social and economic institutions in the Southern Appalachians depend on the variety of benefits provided by its forests, such as abundant, high-quality timber; plentiful and diverse fish and wildlife; extensive recreational opportunities; and a variety of non-timber forest products. These socio-economic concerns have driven substantial research efforts in the Southern Appalachians. As a result, there is an overwhelming body of research available on the ecology and management of Southern Appalachian forests. For example, the Coweeta Hydrologic Laboratory, a center of forest ecology and hydrology research in the region, has produced over 900 publications since 1934 (Stickney et al., 1994). Scientists at the USDA Forest Service, Southern Research Station's Bent Creek Experimental Forest, have produced 287 publications since 1928 on forestry and related research. Nodvin et al. (1993) published a list of some 2500 publications associated with the Great Smoky Mountains National Park alone. Recently, the Southern Appalachian Assessment (SAA) generated nearly 3 GB of information about the status of resources in the Southern Appalachians (Hermann, 1996).

Despite the accumulation of this large body of research knowledge, a gap exists between what scientists know and what the management community is able to apply on the ground (National Research Council, 1990; Hubbard and Dangerfield, 1998). Most research knowledge still resides in highly technical, narrowly focused research publications stored primarily in libraries. As such, the knowledge base retains the fragmented nature of the many separate publications that compose it. In this form, this research knowledge is neither easily accessible nor readily usable because it has not been synthesized and integrated into a coherent, meaningful knowledge structure. Managers frequently express frustration because they lack the time or expertise to synthesize the often-conflicting results they find in the literature. What should emerge as an integrated and coherent body of knowledge appears instead to managers as disconnected, often contradictory, pieces of the "whole" that they need for applied problem solving. Because land managers deal with forest resources in aggregate, they need knowledge in a form that captures the integrative nature of ecosystems and management.

To address this need for more accessible, understandable, condensed, synthesized, and applicable research knowledge, the USDA Forest Service developed the Encyclopedia of Southern Appalachian Forest Ecosystems (ESAFE)—a hyperdocument-based encyclopedia system available on the internet. This project aims to synthesize what we know scientifically about the management and ecology of Southern Appalachian forest ecosystems, organize it logically, and make it universally available at no cost to users. The encyclopedia is designed to be dynamic, so that new or revised content can be submitted directly through the internet, continually updating, expanding, and improving the knowledge base. Unlike most internet-based hyperdocuments, quality control of the encyclopedia is ensured through a complete peer-review process similar to traditional scientific journals.

The main objectives of the encyclopedia are to:

1. organize research knowledge about Southern Appalachian forest ecosystems;
2. synthesize this knowledge into a form that is useful in the problem solving process of forest managers; and
3. make this condensed knowledge accessible to forest managers at no-cost on the internet using a hypertext encyclopedia content management system.

In the following sections, we introduce the basic concepts of knowledge management and briefly discuss the advantages of using hyperdocument technology for managing knowledge. We then introduce E-SAFE, explain its development, peer-review process, and evaluation. We conclude with a discussion of the benefits and limitations of this hyerdocument encyclopedia.

2. The knowledge management problem

Knowledge management is defined as "a set of organizational practices that combine the information processing capacity of information technology with the creative and innovative capacity of people to create, capture, organize, store and retrieve, diffuse, present, and maintain knowledge" (Heinrichs et al., 2003). Codified knowledge is knowledge that has been written down and stored publicly and is available to anyone who knows where to look (Gibbons et al., 2000). Tacit knowledge is private knowledge and may be regarded as residing in the minds of people (Gibbons et al., 2000). For the purposes of this paper, we are dealing primarily with codified knowledge. Knowledge is managed by individuals and organizations in the belief that it will prove useful to solve problems, explore alternative solutions, and make decisions (Gray, 2001). Successful problem solving depends upon (1) having access to the relevant knowledge; (2) understanding the complexity of the problem itself; and (3) knowing how to use this knowledge effectively (Rittel and Webber, 1973; Stock and Rauscher, 1996).

Knowledge management theory and practice focuses on supporting the first element of the problem solving process, namely providing easy access to the right knowledge. This is obviously a grand goal that is rarely completely achieved in real world problem solving, with or without the availability of a knowledge management system. The strategic goal of knowledge management science is to develop the theories and the tools to implement them in order to improve access to the right knowledge at the right time to the right people for the right reasons (Heinrichs et al., 2003). The emergence of the internet has been the key technological development and enabling tool for knowledge management over the last decade. Internet infrastructure, combined with increasingly sophisticated hyperdocument authoring systems, makes web-based scientific knowledge management a new and practical option (Simard, 2000).

Despite the practical importance of access to knowledge and its role in the problem solving process, the application of modern knowledge management methods to forest science is still in its infancy. Many recent reviews of the effectiveness of forest research and extension institutions still emphasize the need for reaching greater numbers of people more efficiently (National Research Council, 1990; Hubbard and Dangerfield, 1998). Despite our best efforts do date, a continuing complaint by end-users of scientific knowledge persists: "I can't find the knowledge I need, when I need it, in a form I can both understand and use to solve my problems".

This situation is largely caused by the "publish-or-perish" reality most researchers operate within. Researchers primarily write for peer-reviewed scholarly journals and produce articles that are usually narrow in scope and highly technical in nature. Efforts to publish synthesis articles in scientific journals, technology transfer bulletins, and notes in paper text format have been frustrated because they go out of date rapidly, are either too general or too narrow, and are expensive to reprint in updated form every few years. As a result, it continues to be very difficult and costly for forest managers to assemble relevant pieces of research knowledge, draw useful conclusions, and translate them into a management solution, particularly within the short time frame most managers have available.

The second element of successful problem solving, defining the degree of complexity of the problem to be solved and concentrating sufficient resources to find satisfactory solutions, is a major research issue in decision support theory (Rittel and Webber, 1973). As problem complexity increases, the cost of finding satisfactory solutions increases and the need for more sophisticated knowledge management and decision support tools increases as well (Simard, 2000; Heinrichs et al., 2003). Problem complexity increases as:

- the number of problem variables increases;
- the number of constraints on the solution set increases;
- the level of uncertainty in data, knowledge, and solution strategies increases;

- the availability of knowledge quantity and quality decreases;
- the availability of human experts decreases; and
- the urgency and impact of the decision increases.

Notice that better scientific knowledge management methods also tend to reduce problem complexity because they improve the availability of knowledge quantity and quality.

Finally, the third element of successful problem solving is the existence of people who know how to effectively translate scientific knowledge into real world performance. Gray (2001) views the problem solving process as a vehicle that connects scientific knowledge with performance. The development and maintenance of problem solving skills in people falls into the educational and training arena. Here too, knowledge management methods can play a significant supporting role. For example, forest managers can directly access hypertext encyclopedia systems and study their organizational structure and content much as one would study a textbook or reference volume. The advantage for managers as students would be that they could be assured that the knowledge management system is being continuously updated by reputable authors with a peer-review process in place to provide quality control. Beyond that, a scientific hypertext encyclopedia can act as a knowledge base for problem-focused, online educational modules. This is the approach that is being taken by members of the U.S. National Web-based Learning Center for Forest and Rangelands (Jackson et al., 2003).

3. Knowledge management and hyperdocuments

Anyone who has accessed the internet has been exposed to hypertext (or hyperdocuments)—a highly nonlinear and interactive mixture of text, graphics, images, video, and audio. Abstractly, a hyperdocument consists of a network of web-based pages (organized collections of information that are each internally self-contained and independently understandable) connected by links (an electronic cross-reference used to connect logically related pages). Links simulate the mental association between pages in the mind of the author. The *structure* of a hyperdocument refers to the organization of pages. Structure commonly takes the form of tables of contents, outlines of pages, graphical diagrams of page relationships, indices, or link organization. The *content* of a hyperdocument refers to the domain-specific material that makes up the subject matter.

Hypertext offers many advantages over paper text that make it more suited for managing scientific knowledge: it can be easily accessed, it occupies little physical space, and it can be published cheaply and rapidly. Unlike linear print media that are static and assumes a single, fixed skill level by the intended audience, hyperdocuments can be readily updated and manipulated to appeal to a variety of users. These characteristics allow hypertext technology to improve the speed and accuracy of data, information, and knowledge management. Several examples of hypertext scientific knowledge management systems in forestry have been previously published, including the Encyclopedia of AI Applications to Forest Science (Rauscher, 1991), the Ecology and Management of Aspen (Rauscher et al., 1995a), the Northeast Decision Model Design Document (Rauscher et al., 1995b), A Hypermedia Reference System to the Forest Ecosystem Management Assessment Team Report (Reynolds et al., 1995), and Oak Regeneration: A Knowledge Synthesis (Rauscher et al., 1997).

As with any media-form, hypertext does have several disadvantages. The single greatest difficulty of hypertext users is navigating to find desired information without getting disoriented. "Getting lost in hyperspace" commonly happens when (1) users follow a chain of links and become distracted from their primary objective and (2) users find themselves unable to return to pages that are of particular interest. The fundamental cause of the navigation problem is the disparity between the author's organizational structure and the user's conceptualization of the knowledge space. The greater the difference between those two views, the more likely the user will get lost in hyperspace. The danger is particularly great for users who are entirely new to the subject matter and have formed no mental maps of their own before using the hyperdocument. This navigation problem can be alleviated if hypertext authors pay careful attention to good global and local navigation devices. Global navigation aids allow readers to (a) determine their present location, (b) identify the location's relation to other materials, (c) return to their starting point, and

(d) explore related pages not directly linked to the current page. Local navigation aids provide the user with access to pages that have some logical relationship with the current page.

A second hypertext issue is how to communicate to the user exactly what is covered by the hypertext and what is not covered. People are used to picking up books or articles that give direct sensory clues as to their size, where they begin, and where they end. The traditional linear authoring style allows rapid browsing for content. A hypertext system provides users few of these clues, and few good designs or technical solutions exist for solving this problem. Therefore, hypertext authors must communicate as much of this information as possible where users are likely to begin. Ideally, the homepage of the hypertext system tells users what the system is about, how large it is, what it contains, and, just as importantly, what it does not contain.

A third hypertext issue is how to enable the user to search for specific topics as quickly and accurately as possible. Powerful and flexible search engines have been developed—almost every hypertext system provides an excellent one. These search engines are modules that are readily available for any hypertext author to use without further need to refine them.

Internet-based hypertext has been shown to be a useful, efficient, and effective form of technology transfer for natural resource management uses (Schmoldt et al., 1998) and a large number of websites have been developed with this focus over the past 10 years. In an attempt to bring some order into this proliferation of sites, the U.S. National Web-based Learning Center for Forest and Rangelands (Jackson et al., 2003) is working to develop a classification of these websites. For example, there are sites with very strong educational objectives offering structured coursework in numerous topics related to natural resources. One of the best examples of on-line coursework is found at the site "http://www.cnr.vt.edu/forestupdate". Other sites specialize in Frequently Asked Questions (FAQ) management. A good example of such a site is "http://www.answerlink.info/". Still other sites specialize in some form of scientific reference management. For example, the Southern Research Station has over 6000 research publications in their reference management system at "http://www.srs.fs.fed.us/" each of which is available in full text, free of charge from the web site. Many sites exist that offer index-like listings of numerous other sites with natural resource management content. The southern regional forestry office maintains a site at "forestryindex.net" that organizes other sites, allows searches across these sites for specific information, and allows developers of natural resource sites to add their own site to this index. Still other sites exist that organize natural resource data by geographic location, see, for example, "climchange.cr.usgs.gov/data/atlas/little". Many sites provide voluminous and very detailed data about trees, insects, diseases, etc., for example, "fhpr8.srs.fs.fed.us/idotis/insects.html". Sites that organize simulation models for downloading are also available in abundance. A good example of this type of site is found at " www.fs.fed.us/fmsc/fvs/software/varfiles.php" that allows users to download the Forest Vegetation Simulator. However, few, if any, currently available sites are specifically focused on the internet-based management of scientific knowledge that is peer-reviewed and continually updated.

4. The Encyclopedia of Southern Appalachian Forest Ecosystems

The Encyclopedia of Southern Appalachian Forest Ecosystems (ESAFE, http://www.forestencyclopedia.net) is composed of summaries of hundreds of topic areas compiled from over 5000 literature sources by over 15 authors. As of this writing (January 2004), ESAFE has 1100 pages of content that includes over 150 tables, 150 figures, 3000 internal hyperlinks, and 1800 external hyperlinks. This content base is continually being expanded, improved, and updated with peer-reviewed material.

Developing ESAFE required a mixture of planning required for writing a book and that required for a software project. In this section, we first discuss the former—the processes of developing structure and content for ESAFE. That leads to a discussion of global and local navigation. Finally, we summarize the content management system software we developed to manage authoring, peer-review, and the publishing process.

4.1. Thematic scope and target audience of ESAFE

ESAFE content is designed to provide a concise state-of-the-knowledge synthesis of Southern Appalachian research. As explained clearly by its name, ESAFE focuses on the forest ecosystems of the Southern Appalachians. Although traditional forestry topics, such as oak silviculture, are covered in more detail, we have included a variety of other forest-related topics. These include soils, geology, classification of natural communities, environmental history, wildlife ecology and management, management of aquatic resources, non-timber forest products, old-growth forests, biodiversity, aesthetics, disturbance, biogeochemical cycling, air quality, insects and diseases, exotic species, decision support, recreation, sociology, and economics. The dynamic content management system (see Section 4.4) will allow these topics to be expanded as new content is created, peer-reviewed, and accepted. Users can get an up-to-date overview of the completeness of these topics by accessing a link from the encyclopedia's homepage.

The main audiences targeted by the encyclopedia are forest managers. However, one of the advantages of using a hypertext format is that audiences with differing levels of experience can be targeted. Therefore, we also expect that researchers, landowners, local and regional policy makers, students, and the general public will find particular sections of the encyclopedia useful.

4.2. Content development

Once the scope of the encyclopedia was established, we developed an extensive outline of the proposed encyclopedia content. This outline was translated into a hierarchical hyperdocument structure using Microsoft Frontpage ©, an html editor. Although the technological needs of the encyclopedia eventually outgrew the features offered by Frontpage © as explained later, this software offered a convenient navigational view that was pivotal for frequently manipulating the encyclopedia's structure early in its development. Recognizing that an endless number of possible structures exist for such a broad domain of knowledge, we approached the organization of the content from both a subject matter perspective and users' perspective. For example, we organized resource management-related knowledge into a major section, apart from more basic ecological knowledge (see Section 4.3). Of course, relevant ecological content is easily accessible via hyperlinks from related resource management content, therefore the structure we proposed for the encyclopedia does not prevent users from accessing content in an order that makes more logical sense for their purpose, i.e., users can chart their own navigational path through the encyclopedia. Realizing this, it was easier to decide upon a reasonable structure for the encyclopedia of the myriad of possibilities.

Once the structure for the encyclopedia was developed, we began to fill this structure with content. The encyclopedia's content originates from three different sources: original syntheses written specifically for the encyclopedia by the principle investigators or other experts (70%); the previously published hyperdocument, Oak Regeneration: A Knowledge Synthesis (Rauscher et al., 1997) (15%); and content excerpted from sources in the public domain and modified to follow the encyclopedia's format (15%). The hierarchical structure of ESAFE made it possible to divide content into sections that were assigned to individual authors. These authors could then expand the outline and develop the structure to complete their section.

Authors used their own approaches to synthesizing content, ranging from writing original literature reviews of primary literature to summarizing existing literature reviews. At least half of the encyclopedia's content was written by the principal investigators using a technique devised specifically for hypertext. In this technique, electronic versions of source material were copied, paragraph-by-paragraph, into the appropriate pages of the Frontpage © hyperdocument structure. After placing hundreds of source documents this way, each page in the hyperdocument contained numerous paragraphs from different source material roughly covering the same subject matter. We then organized this material, synthesized the main ideas, and wrote original summaries with appropriate citations from the original literature sources. These citations are hyperlinked directly to bibliographic information, and publications that are in the public domain will be linked to on-line full-text documents.

Regardless of the authors' approach to synthesizing literature, the critical step in organizing and presenting this content was to make sure it all followed a standard look and feel. Since encyclopedia users can jump between pages written by different authors with the click of a mouse, it is important that the content pages are "authorless" or they are written in a similar voice. To do this, we developed a set of authoring rules to assist both authors and editors with writing and organizing content pages. These authoring guidelines were also designed to ensure that readers could comprehend content pages quickly and easily. For example, no more than three–four screens (900–1200 words), preferably fewer, of information are contained in a single page; longer pages are split along logical lines into two or more detailed pages. Since hypertext should be more visual than paper text, key terms are bolded; key concepts italicized; and bulleted lists, charts, tables, graphs, figures, photographs, or pictographs are used to clarify, streamline, and condense the text. Hyperlinks provide an additional visual cue that is also familiar to users.

One of the most important authoring rules was that each page be independently understandable and self-contained. Authors cannot rely on sequential reading to present material, since readers arrive at a particular page by linking from many different directions (hypertext pages). Also, unlike paper text documents, where much verbiage is used for transition and contextual placement of facts or concepts, hypertext pages contain only pertinent facts and concepts—if something must be explained more fully, the author simply creates a new page and a link. These authoring guidelines were particularly helpful for many authors who had little or no previous experience with writing hypertext. Content excerpted from the public domain was also edited to follow this uniform style.

4.3. Navigation in ESAFE

Topics in ESAFE are organized into six major sections: The Landscape, Resource Management, Ecology, Forest Health, Social Science, and Economics. These six sections are represented in a drop-down menu that is visible to users at all times (Fig. 1).

Content within each of these major sections is organized in a hierarchical structure, where each page has one parent page and one or more child pages below it. This tree-like structure is represented as a linked collapsible menu in the left frame of Fig. 1. These menus change accordingly as users browse between the six major sections. This collapsible menu and the drop-down menu serve as the encyclopedia's main global navigation aids. Other examples of global navigation aids used in the encyclopedia are the table of contents, figure and table indices, and full-text search tools. The table of contents is the hierarchical outline of links to all pages in the encyclopedia and provides the user with a complete view of the encyclopedia structure. The figure and table indices look and operate in similar fashion. The full-text search tool provides more options for search than does the search box at the top of each page; advanced search capabilities are described on a linked "tips" page.

Local navigation is provided by hyperlinks anchored within encyclopedia pages. These links can be used to move sequentially within a subject area, to move laterally within the encyclopedia to related topics, or to link to web pages outside ESAFE. Organizational pages are used to simplify local navigation. These pages, which organize links to child pages (subtopics), provide a roadmap to users, helping them understand the structure of subsections and giving them enough information to decide if they want to read further by accessing links. Content pages, generally at the lowest level of the outline hierarchy, cover an individual topic to some depth and may contain links to other related pages. Accessing local navigation links move the user within ESAFE. The new location is represented in the linked collapsible menu. If users browse among the six major sections of the encyclopedia, their location is also highlighted in the main drop-down menu. When a link reaches outside ESAFE, the different frame of the host site signals the move.

4.4. Content management infrastructure

The initial infrastructure for ESAFE was created using static HTML publishing methodology. Authors created content using the Microsoft® FrontPage HTML editor. Individual authors then delivered completed content electronically to the project manager, who then integrated these pieces into a master structure. This master structure was then used to update the on-line system. The online infrastructure was developed using a server-side scripting language (PHP, or PHP Hypertext Preprocessor; Ratschiller and Gerken, 2000) in combination with MySQL® relational database software.

This infrastructure quickly proved to be inadequate for planned expansion of the initial ESAFE system. Numerous authors providing a continuous stream of

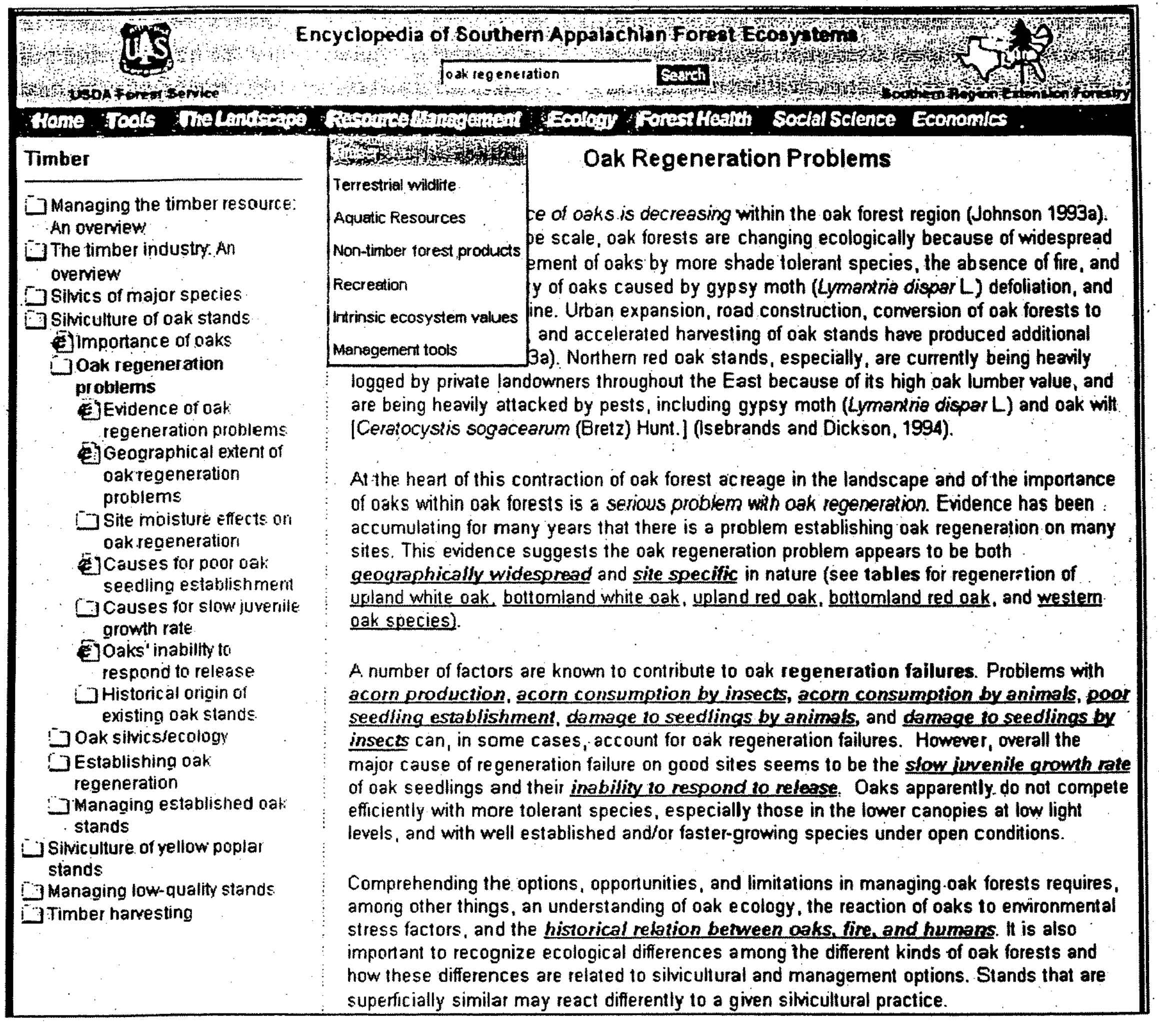

Fig. 1. Sample organizational page in Encyclopedia of Southern Appalachian Forest Ecosystems (ESAFE). The drop-down menu on the top bar and linked collapsible menu in the left frame serve as the encyclopedia's main global navigation aids. The collapsible menu in the left frame changes accordingly as users browse between the six major sections organized in the top bar. In this example, the page "Oak Regeneration Problems" is found within the "Timber" subsection (left frame) of the "Resource Management" major section (top bar). User help, table of contents, figure and table indices, full-text search tools, and a user-feedback form are accessible under the "Tools" tab in the top bar.

content required a complete content management system that was dynamic, easy to update, and easy to maintain. After examining many competing approaches, we chose the Zope web application framework (Spicklemire et al., 2001) to develop our second-generation encyclopedia infrastructure. Using Zope, we designed a content management system (CMS) that would: (1) allow authors to create, edit, and submit multiple types of content inside the system; and (2) allow a complete peer-review and publishing cycle to occur inside the system. In a companion paper, Jordin et al. (2003) provide technical details of how Zope was used to create this CMS. Here, we highlight how the CMS works.

4.5. Peer-reviewing, publishing, and updating content

ESAFE is built on a CMS that facilitates a peer-review process paralleling that of traditional paper journals. The Zope CMS uses custom workflows as the foundation for the peer-review and publishing process. A workflow defines rules for each type of content that can be created inside the encyclopedia. Here, for example, we explain the workflow for an encyclopedia page (Fig. 2).

Authors begin the publishing process when they submit a page (web-page) and its supporting content (child pages). They designate the intended section in ESAFE by noting a parent page. Next, the corresponding section editor provides commentary, passes the page to another section editor, rejects the submission, or accepts it for review. After a section editor has accepted the page, he or she designates external reviewers to assess the document and supporting content for its scientific merit. As typical for peer-review journals, the section editor collates the reviewers' comments for the author. After a critical number of reviewers accept the page and the author has made the requested revisions, it progresses to a technical editor who edits the page for appropriate style and form, grammar, etc. After the section editor approves the technical edits, the page is submitted to the senior editor for review and final acceptance. If at any point in the workflow a page is rejected, it must repeat the entire process to be published.

The various tasks contributors are allowed to perform within the Zope CMS are predetermined by one or more roles each is assigned: author, peer-reviewer, technical editor, section editor, or editor-in-chief. For example, authors may submit content, but cannot modify any content other than their own. Authors can also check on the status of their own pages in the publishing process whenever they choose, but are restricted from certain comments in order to keep reviewers anonymous. Section editors have access to more material than do authors and reviewers. Zope regulates access to content based on a contributor's role. Roles are identified within the Zope CMS by usernames and passwords.

The Zope CMS also provides a mechanism to update existing content. Once a page is published, any contributor with approved access will be able to create a copy of the content onto their desktop area in order to make additions or changes. As with original content, these revisions to existing content must go through the appropriate channels of peer-review and editing before replacing the original content in the encyclopedia structure. The original published version remains accessible by all users during the process. To prevent multiple authors from editing the same content at once, a lock is placed on the published version, indicating that it is being edited. A unique feature that will be implemented in the new system will allow encyclopedia users to retrieve previous versions of content, if it exists, so that the change of knowledge over time can be documented.

Once revised content completes the peer-review cycle, the original content is converted into an archived page. When a user views any page that contains an archived version, they are notified by a hyperlink to the entire lineage of archived pages. Page archives are omitted from the catalog to make sure they are not returned in search results. By browsing this collection of archives, a user can get a sense of the direction of research and changes in what is known about the topic in question.

5. End-user evaluation

We asked representatives of the target audience (forest managers, scientists, other practitioners, and laypersons) to evaluate the encyclopedia during the summer of 2002. Users were directed to an on-line evaluation and open-ended comment form from the home page, where they were asked to review the encyclopedia and comment on how well it achieved its objectives and met users' needs. Users were asked to comment on several aspects of navigation and content: is the information easy to find, easy to understand, sufficient for the user's needs, and helpful in decision-making? Is the information well organized and easy to navigate?

A total of 32 comments were received within 3 months of the start of the evaluation period. Comments were received from a number of different sources including USDA Forest Service (9), Other Federal (Military) (2), University (7), Private (Consulting Foresters and Forest Industry) (4), Nongovernment Conservation Groups (1), State Forestry (2), Anonymous (5) and Unknown (2). In addition, comments were solicited from a group of managers attending a USDA Forest Service sponsored training session in the spring of 2002.

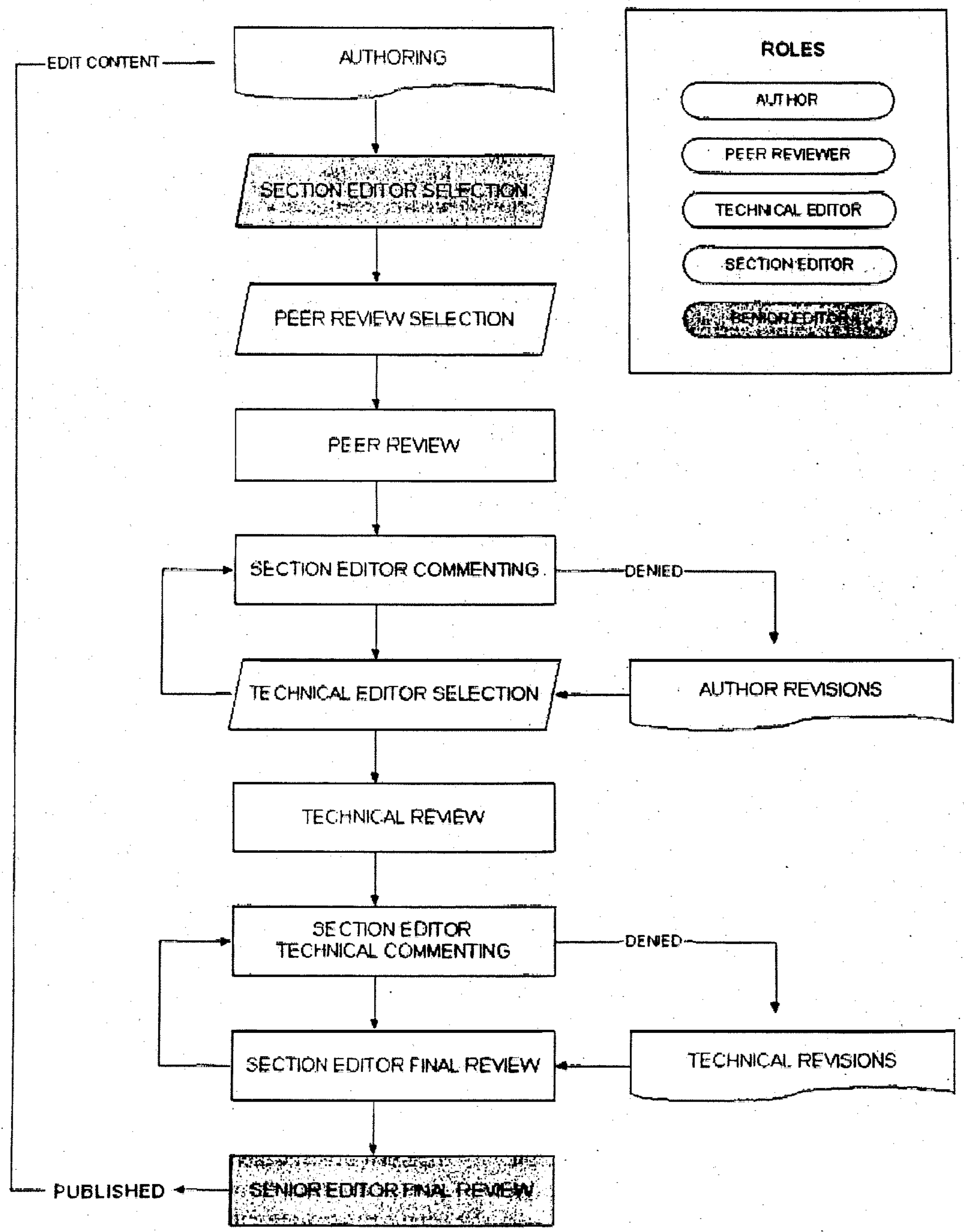

Fig. 2. Workflow of the content management system (CMS) for the Encyclopedia of Southern Appalachian Forest Ecosystems (ESAFE). The workflow depicts the stages a page or section of linked pages follows for peer-review, technical editing, and final publishing. The color of each stage represents what role is responsible for completing the actions of that stage (author, peer-reviewer, technical editor, section editor, or senior editor). Access to pages in this workflow are defined through these roles, which are identified within the CMS by usernames and passwords.

Overall, users across all groups were impressed with the project as a whole and positive about the potential uses of the encyclopedia. No reviewer felt that this was an unneeded tool. Many commented on the innovative nature of the resource and its immediate use to them as scientists, managers, and educators. Most of the evaluation comments came from forest managers, the primary audience for ESAFE. However, a significant number of comments were received from scientists. Scientists were often interested in how well their own field of specialization was represented. But several scientist evaluators also indicated that they found sections outside their own specialty useful as a source of knowledge, queries by managers, and for preparing background sections of reports to administrators. Several respondents were University professors who felt that ESAFE would be a valuable additional resource for their students to augment course material. We had very few landowners respond to the evaluation as of this publication. The two that have responded were very enthusiastic about the material they read and claimed that it contributed to their understanding of management prescriptions recommended for their own land by service foresters.

Respondents also suggested specific improvements, some of which are summarized here:

- more research and case studies;
- more bibliographic references, links to journal articles/other resources and literature cited;
- current level of detail was sufficient for general public but not necessarily for professional;
- link to online Society of American Foresters Dictionary, if possible;
- move to a database system rather than flat-text file system;
- "old-fashioned" index was desired;
- more hypercontent rather than hypertext (graphics, video, audio, multimedia production, etc.);
- heavier use of graphics and images; and
- more content on small mammals, ecological site index, soils, policy/decision process, white pine and hemlock, pine/hardwood forests.

Each respondent who supplied an e-mail address will be informed about any remedial actions being taken to address their concerns. Through this process, we hope to establish an ongoing community of professionals willing to provide valuable feedback on this project on a periodic basis. The electronic comment form will remain on the site to encourage new user input and review.

This first evaluation of ESAFE did not involve a structured test for problem solving. We were interested in how well ESAFE supported knowledge-based learning rather than problem solving. It can be best described as an evaluation for general utility focusing on content, organization, and ease of navigation. However, future evaluations will focus specifically on problem solving. For example, a very common problem in the Southern Appalachian region is deciding how to obtain oak regeneration on a specific forest site. There is a section in ESAFE on planning for oak regeneration and evaluating the potential for oak on a variety of sites. We will evaluate how quickly a user can find this section and then, having found it, how useful the information is in helping to solve that user's problem. Another feature that we plan to implement is a Frequently Asked Questions feature in ESAFE. This section will provide another way to feature frequently encountered problems and their solutions. However, the list of potential problems that users have is essentially endless. It will take years of problem identification and solution development before ESAFE will likely be able to have ready-made answers to even the majority of specific problems that users might bring to the system. A gradual, steady improvement in the depth and breadth of this system is envisioned and made possible by the continuous, peer-reviewed, updating process described above.

6. Summary and conclusions

The Encyclopedia of Southern Appalachian Forest Ecosystems constitutes a framework for organizing knowledge about Southern Appalachian forests and improving access to that knowledge. We developed ESAFE to demonstrate that hypertext technology is an efficient and effective way to manage scientific knowledge by making it accessible to resource managers in a format that is easy to understand.

The ESAFE system was developed along two fronts: content development and content management. Content on a full range of forest ecology and management subjects was developed as either (1) original contributions of researchers and experts; (2) a published hyperdocument (Rauscher et al., 1997); or (3) material excerpted from published reviews in the public domain. Author guidelines ensure that each page is independently understandable and self-contained. Content is organized in a hierarchical knowledge structure that individual authors develop, as they create content. This structure and imbedded hyperlinks facilitate navigation by users. Content management evolved into a full CMS, designed using Zope, that manages content per se with established workflows for authoring, editing, reviewing, publishing, and updating (Fig. 2).

Compared to other efforts (Rauscher, 1991; Rauscher et al., 1995a,b; Rauscher et al., 1997), this hypertext encyclopedia is unique in that we have built a sufficiently complex pilot to constitute a successful proof of concept. The large number of pages (over 1100 and growing) and links is sufficient to disorient most readers. Yet, our global and local navigation tools allow users to (1) navigate the structure without getting lost; (2) learn the knowledge structure quickly so they can form a good mental map of the science; (3) search for particular pieces of knowledge quickly and efficiently; and (4) learn quickly what content is in the encyclopedia and what is not.

Furthermore, we have implemented a content management infrastructure that will support a well-designed document control workflow. The system has no foreseeable upper limits on size or scope—it is completely expandable. The workflow incorporates a peer-review process that parallels what is being developed for paper and electronic journals.

This system has the potential to revolutionize how research scientists deliver information and synthesize knowledge for our clients who must solve problems. In the past, research scientists have done so on a time-consuming ad hoc basis, responding to specific requests for information and advice. Furthermore, although forest managers generally have access to the internet, they are often unable to visit libraries to meet their information needs. In workshops and other settings, these users express frustration because they lack the time or expertise to synthesize the often-conflicting results they find in the literature. With tools like ESAFE, busy forest managers can more easily find answers to problems from their own desks. Encyclopedia content provides brief descriptions of recently completed research that can reach users more quickly and directly than with traditional print media. The structure of ESAFE places new information in the proper context with linkages to related information. The peer-review process of the CMS ensures that the information published is scientifically credible. The encyclopedia is both dynamic, making future updates easy, and nonlinear, allowing a greater level of knowledge integration than existing print media can accommodate.

The end-user evaluation process, although not necessarily ideal, demonstrated that internet-based hypertext technology makes information more accessible to users (objective 3) than does the traditional paper-text technology transfer system. Some comments like the request for an "old-fashioned" index may reflect a desire by users for familiar paper text tools, which will change as they become more familiar with searching and browsing tools. By and large, though, most suggestions concerned issues of content, which will be resolved as we move from this prototype to a more complete version. Evaluation is an on-going process in ESAFE; we continue to receive comments from an expanding base of users, including non-professionals. The dynamic nature of ESAFE will allow us to accommodate this variety of potential users.

Limits of the encyclopedia system are primarily related to content and creation of content. Some topics are presently covered less completely than others, limiting the usefulness for some problems; but that will change as more content is added. Creating content requires considerable effort by authors, reviewers, and editors who are themselves experts in their content areas. Relatively sophisticated staff is needed for long-term maintenance; otherwise, ESAFE could easily become obsolete. In contrast, we have encountered few limits related to the CMS—we can easily modify the CMS in Zope to meet our needs and those of users. As the internet advances in the next few years, our CMS can be modified to allow execution of models, further enhancing the decision-support capabilities of ESAFE.

Knowledge management tools like ESAFE can play a significant supporting role for problem solving and decision-making, especially where we cannot anticipate the range of problems users might bring to the system. Our needs for knowledge management in the Southern Appalachian ecosystem are not unique, and the concepts and techniques developed in this encyclopedia project can be broadly applied to other knowledge domains. Interest in this work is gaining momentum in the region and is beginning to achieve national attention in the U.S. The USDA Forest Service recently initiated work on a Fire Science Encyclopedia and plans are underway for a Central Hardwoods Encyclopedia, each of which will generate unique issues for development of improved knowledge management technology.

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